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RANGE ESTIMATION OF FAMILIAR TARGETS PRESENTED AGAINST A BLACK BACKGROUND

by Gary P. Beasley and Jack E. Pennington

Langley Research Center

Langley Station, Hampton, Va.

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SUMMARY

A series of tests has been conducted to determine the human ability to judge range with no cues except the apparent size of the object viewed. This visual situation could occur in many space operations. Subjects were asked to estimate the distance to targets of known size placed at random distances and uniformly illuminated. The targets were a plane triangle, a disk, and three proportional cylinders. The tests were conducted in a 2800-foot-long darkened building.

Results show that subjects tended to overestimate the range of the smaller models and to underestimate the range of the larger models. Subjects were able to estimate accurately the range of receding targets at much greater ranges than that of approaching targets.

It appears possible to apply the pilot's visual acuity (the ability to distinguish fine detail) to make estimates accurate over a greater range. The point at which the size and shape of a particular target can first be resolved could determine a specific range on which subsequent estimates could be based. This possibility was not investigated in this test series, but such a technique, based on test results, is suggested.

INTRODUCTION

The visual environment which astronauts encounter in space differs somewhat from visual conditions on earth. Among these differences are a lack of shades of gray, greater contrasts, and the lack of surrounding references for distance estimates. The lack of reference objects, or gradients, which are usually used for distance judgments requires that distance to an object (or range) in space must be based upon the apparent size of the object viewed. Since the ability to estimate range accurately is desirable in space operations such as docking, repair, and extravehicular locomotion, a study has been made to determine the human ability to judge range with no cues except the apparent size of the object viewed.

Previous studies (refs. 1 to 3) have investigated pilots' ability to utilize visual information for space navigation and rendezvous control. Additional

studies (ref. 4) have been made to determine the feasibility of visual-docking techniques from about a 300-foot range. Although piloted docking control requires range estimations, either consciously or unconsciously, the simulations reported in reference 4 were concerned only with completion of the docking maneuver and not of estimation accuracies. In reference 5 is reported an investigation of the mean error in estimating the range of two plane targets illuminated at a limited number of points between a 100-foot and an 800-foot range in a darkened corridor.

In the present study, subjects were asked to estimate the range of targets of known size as they were shown, one at a time, uniformly illuminated at random distances up to 1300 feet in a darkened environment. A disk, a triangle, and three proportional cylinders were used in the tests. The objectives of the study were to determine (1) both the mean error and the standard deviation of the range estimates from 0 up to about 1300 feet, (2) the effect of target size on range estimates, (3) the effect of target color on estimates, and (4) the effect of varied lighting contrasts against a black background.

APPARATUS

Tests were conducted in the high-speed phenomena division of the David Taylor model basin at Langley Air Force Base. (See fig. 1.) The facility contains a concrete trough which is roughly a half-cylinder 12 feet deep, 24 feet wide at the top, and 2800 feet long. During normal operation the trough is filled with water, but for these tests it was drained and the subjects were seated on a platform near the bottom of the trough. The targets were moved to various distances where they were uniformly illuminated for observations.

The targets employed (fig. 2) were a 1-foot-diameter circle, a triangle of area equal to that of the circle, and three cylinders, 5, $2\frac{1}{2}$, and $1\frac{1}{4}$ feet in length, which could be assumed to be 1/5-, 1/10-, and 1/20-scale models of a 25-foot-long, 5-foot-diameter booster similar to the Agena. The targets were painted flat white on one side and fluorescent orange on the other side, so that the effect of color on estimates could be studied. Figure 3 shows the percent reflectance of the orange paint as a function of wavelength.

The target was illuminated with a sealed-beam lantern whose spectral distribution is shown in figure 4.

TEST PROCEDURE

Six subjects participated in the tests. (A test consisted of observations at a series of distances.) All were engineers with no previous special training for these tests, and all had at least 20/20 vision. The subjects were allowed a firsthand examination of the targets before the tests were conducted so that they might become familiar with the actual size, shape, and color of the targets, but there were no pretest practice estimations. All six subjects did not

take part in every test, but at least four of the subjects participated in every test. Table I shows the tests in which each subject participated. It should be noted that each test involved 10 to 20 observations and that the entire study consisted of about 1200 observations.

Tests were made at night with the subjects seated on a platform near the bottom of the model-basin trough. After the target to be viewed was shown to the subjects, all lights were turned off while the target was moved to a preselected test distance. After reaching the selected test distance, the target was illuminated with the sealed-beam lantern directed down the basin in such a way that the subjects saw the target apparently suspended against a completely black background. The disk and the triangle were presented with the plane surface perpendicular to the subjects' line of sight; cylinders were presented with the center line horizontal and perpendicular to the line of sight. The subjects then estimated the range based only on the apparent size of the illuminated target. The light was then turned off and each subject, with the aid of a dim red light, recorded his estimated range on a data sheet. Each subject did not reveal his estimate to the others.

The movement required to reposition a target between observations naturally generated some noise. This noise was not felt to be a problem, however, because the basin walls caused echoes which made it difficult to determine the direction of motion and the same interval and noise between observations was maintained, regardless of target-range change.

Tests were made with targets both approaching the subjects and receding. Although the general trend was in one direction for each test, the motion was sometimes reversed, resulting in a somewhat irregular pattern of separation distances in each test. This complicated pattern of presentation prevented the subjects from guessing, or predicting, the succeeding range. This pattern can be seen in table II which shows a typical test using the 1.25-foot-cylinder target.

The primary series of tests involved all targets and both colors (white and orange), both approaching and receding from the subjects. A second series of tests was designed for the study of the effects of relative brightness or contrast on the estimates. This series of tests was made with the 2.5-foot cylinder approaching the subjects. For these tests a rheostat was placed in the powerline of the lantern so that two levels of lantern brightness could be used. The two levels used were a high brightness level (0.14 candle/sq ft) and a low brightness level (about 0.007 candle/sq ft). The low brightness level was such that the outline of the target was just distinct. The high brightness level was used for all other tests.

ANALYSIS

Since several observations (approximately eight or ten) were made for each distance in each test, the easiest and most logical result is the average (or mean) of all the estimates. However, the average estimation, which in many cases fell very close to the true distance, did not reflect the wide variance in

estimates because of "compensating" judgment errors among the individuals. Therefore, in order to include the variance and to neglect the overestimation and underestimation compensation, a digital computer program was run to obtain the standard deviation of the estimates.

The standard deviation was computed from the following equation (ref. 6):

$$\sigma = \left[\frac{1}{n - 1} \sum_{i=1}^{n} (x_i - \bar{x})^2\right]^{1/2}$$

where

σ standard deviation

n number of estimations

$\bar{x}$ mean estimate

x_i individual estimation

RESULTS

Estimations With Constant Target Illumination

Tests were made with two target colors, white and orange. All data indicate, and the subjects agreed, that the color of the targets had no noticeable effect on estimates. Therefore, the data for both colors are combined in the following results.

In figure 5 the average estimated range is plotted against the true range of the three cylindrical targets. Correct average estimates lie along the solid line. The figure shows a tendency which is apparent throughout the study - a tendency toward overestimating the range of the small (1/20-scale) target and underestimating the range of the medium and large (1/10- and 1/5-scale) targets. All average estimates were good within the nearest 100 feet. It is interesting to note that at a range of 795 feet the average estimate for the small target (1/20-scale cylinder) was 800 feet. The figure does not show, however, that individual estimates ranged from 500 to 1100 feet. This variance tends to agree with reference 5, in which a similar test produced individual ranging accuracy from 3 percent to 247 percent of the true value. Thus, as mentioned earlier, a means of analyzing this data scatter was necessary. In this investigation the standard deviation is utilized.

Figure 6 shows the average percent error and the standard deviation, both expressed as a percent of true range for each model, plotted against the true range. An average overestimation is indicated by a positive average error and an underestimation, by a negative percent average error. The points designated by circles show estimates made during a test in which the target was approaching the subject in discrete increments, and the diamonds represent estimates made

for a receding target that was also moved in discrete steps. A solid symbol shows a reversal of direction from the general trend. For instance, while a series of tests was being conducted in which the 1/20-scale cylinder was receding from the subjects, after a judgment at 395 feet the target was moved to 295 feet for the next estimate. (See fig. 6(a).) Therefore, the diamond data symbol (for a receding target) which is shown open for the 395-foot estimate is shown solid for the 295-foot estimate because the general trend of the target movement (receding) was reversed for that observation. Thus, the shaded diamonds are effectively circles, and vice versa. As was noted earlier, "approaching" or "receding" refer to the general trend of presentation or could be considered to refer to the relation between the initial and final target positions. Targets were stationary during each observation, so estimates were based only upon target position and not target velocity.

Figure 6(a) shows several interesting results for the 1/20-scale target. First, there was a strong tendency to overestimate the range of the approaching target, whereas the overestimations for the receding target tended to be much less. Second, the standard deviation for the receding target was from 10 to 20 percent from near zero range to 200 feet and between about 10 and 25 percent from a 200- to 600-foot range. Little credence can be given to estimations beyond 400 or 500 feet because of the apparent loss of shape of the target in this region. Third, the standard deviation for the approaching target has a definite trend; the initial deviation starts high and then increases even more as the true range decreases. Then, as the shape of the object became more apparent, the standard deviation decreased until it was within 25 percent within the last 150 feet. An increase in accuracy was to be expected in this range since both full-scale dynamic and closed-circuit-television simulations of the docking maneuver have demonstrated that a pilot can complete the maneuver visually. (See ref. 4.)

Figure 6(b) is the average error and standard deviation plotted against the true range for the intermediate cylindrical (1/10-scale) target. As indicated in the figure, subjects tended to underestimate the range of the receding target but, on the average, were more accurate for the approaching target. This figure also shows that the standard deviation for the receding target was less than about 20 percent out to 1100 feet. This increased region of accuracy over the 1/20-scale target is indicative of the fact that the 1/10-scale target retained its apparent shape to the maximum test distance (1200 feet). The standard deviation for the approaching target exhibits an interesting trend. The standard deviation at the extreme distances (1200 to 800 feet) are less than 20 percent; then, as the range decreases, the standard deviation increases to a maximum at 175 feet and drops again to 20 percent at 55 feet.

Figure 6(c) gives the results for the 1/5-scale target. The tendency, as shown by the average error, was to underestimate rather than overestimate the range, as was done with the 1/20-scale target. Except for the estimations between 0 and 75 feet, the standard deviations for the receding target were less than 20 percent, whereas the bulk of the estimations for the approaching model in the range from 0 to 900 feet was under 30 percent. These long ranges of relative accuracy again indicate that the target retained its apparent shape to the subjects throughout the test. The standard deviation for the apparent target beyond 900 feet showed a marked increase out to the greatest distance of 1300 feet.

Figure 6(d) contains the errors plotted for the 1-foot-diameter disk. As indicated by the figure, the average errors are nearly all positive, indicating overestimation of range; the estimation errors for the approaching target were larger. The standard deviation for the receding target was between 10 and 20 percent for ranges between 50 and 400 feet and was between 20 and 30 percent from 500 to 1100 feet. The standard deviation for the approaching target was for the most part greater than 40 percent and increased as the range decreased. These large deviations could be attributed to the apparent shape of the target, that is, the target appeared initially as a point object and essentially remained as such until the subjects saw changes in the apparent size of the disk.

Figure 6(e) gives the results obtained for a triangle having the same area as that of the 1-foot-diameter disk. As indicated in the figure, there was a tendency to overestimate the range for both receding and approaching targets. The values of the standard deviation for the triangle are generally much lower than those for the disk shown in figure 6(d). This smaller variance is probably due to the presence of the discernible shape of the triangle. It is seen in figure 6(e) that the standard deviation of the approaching target decreases to a minimum at one point around 795 feet. This decrease may be coincidental, but at this point all the subjects were able to discern the triangular shape for the first time as the target approached. Beyond this distance the target was unresolved and appeared as a circular or point source of light. The subjects did not know the distance at which this phenomenon would occur or even that it would occur. Thus, it may be feasible to use a particular geometric shape, perhaps on the side of an object viewed in space, so that when the observer could recognize the true shape he would know (within certain limits) the distance to the object.

The question then arises whether the accuracy of range estimates could be improved if the pilot was able to determine the range at some specific point during closure. The data in figure 7 indicate an affirmative answer. As noted earlier, during a test sequence with either an approaching or receding target, the direction of motion was occasionally reversed, resulting in a back-and-forth pattern of movement. In figure 7 a positive displacement on the ordinate indicates that the target was moved the reversed displacement distance away from the subjects to the range shown on the abscissa. For example, consider the point at the 495-foot range. During this particular test the triangle was being moved away (receding) from the subjects. After an observation at 595 feet the target was brought back to 495 feet for the observation plotted in figure 7. The arrow represents both the direction and magnitude of the estimated change. In the example considered, the subjects estimated that the target had approached 81 feet (rather than the true 100 feet) from the previous estimate. The points are plotted for the tests made with the disk, the triangle, and the 1/20-scale cylinder. The dashed lines were drawn where two estimates were made at any particular range. The only point at which an incorrect judgment of the direction of motion occurred is at 255 feet. All other estimates were in the correct direction and close, in most cases, to the correct distance.

This accuracy in estimation of displacement distance indicates that after the first estimate the subjects made subsequent estimates by adding the change in range to the previously estimated range. This situation is encountered in many estimation problems, and psychologists refer to this phenomenon as an "anchoring" effect because the subjects base, or anchor, all judgments on some

original estimate. This anchoring effect probably accounts for the average error trends in figure 6. When the target was close (within 50 feet), the subjects were able to estimate the range accurately. Although the error may be as high as 25 to 30 percent of the true range, this percentage still represents only a small range error (12 to 15 feet). This accurate initial estimate for a receding target would account for the reasonable accuracy of the estimates for the receding targets as the range increased. Conversely, the poor initial estimate in the case of an approaching target resulted in continued poor estimates as range continued to decrease. In fact, even if the subsequent estimates of the change in range were equal to the change in true range, as the range decreased the ratio of error in range to the true range would increase, which was found to occur with all targets. It appears reasonable to expect, then, that if the pilot could accurately determine the true range at some point on the approaching track, then following estimates should be much more reliable than those which occurred during these tests. Results indicate the need for further study to determine if the error could be reduced for an incoming target by training the subject to anchor the estimates for an incoming target on some acuity characteristic (such as true shape) which is known to occur at a particular range. Time did not permit further studies in this area.

It should be recognized that the ability to distinguish fine detail (visual acuity) depends on several factors (ref. 7) which must be considered in any situation in which a shape or outline must be resolved. These factors include: (1) the distance at which acuity is involved (accommodation of the eye effects acuity within 20 feet); (2) retinal location (acuity drops off for objects in the periphery of the eye); (3) viewing time (an object is more visible the longer it is viewed); (4) background luminance; (5) luminance, or "brightness," contrast (acuity can be improved by increasing the background luminance or the luminance contrast); (6) chromatic contrast and color of background (there are indications that total effective contrast is a function of both luminance contrast and chromatic contrast). Although these are not the only factors which affect visual acuity, they should be considered in any situation involving target resolution or visual range estimates.

It has been suggested that overestimation and underestimation may be due to the relative composition of the stimulus sets and not an absolute property of the particular target sizes. References 8 and 9, although not directly related to the study here, cite investigations of the effect of relative composition within sets.

Effects of Varied Target Illumination

The results of the brief study on the effects of target brightness on the estimation of range are indicated in figure 8. These tests were made with the 1/10-scale target approaching the subjects. Two target brightness levels were used, rather than the fixed (high) level employed in all other tests. A random sequence of high and low target brightness was used during this test series. The shaded data points represent observations made at the lower brightness level. The figure shows a much poorer average estimation for the observations with the lower brightness level than for the brighter targets shown in figure 6(b). Both

the average error and the standard deviation for the target at all ranges were much higher than those occurring with a fixed brightness level. (Compare figures 6(b) and 8.) Estimates for the bright observation at 700 feet, for instance, ranged from 400 feet to 1725 feet. This wide variation indicates the significant effect of change in contrast. (It might be noted that the orange target remained decidedly orange even at the low brightness level.) It is possible that conditions in space operations could present a range of target contrasts which could reduce estimation accuracy.

CONCLUSIONS

A series of tests has been conducted to determine the human ability to judge range with no cues except the apparent size of the object viewed. The study indicates the following results:

1. There was a general trend for subjects to overestimate the range as an inverse function of the size; that is, the smaller the target, the more the subjects tended to overestimate at a given range. The tendency to underestimate the range to a large target would provide a safety factor in space application, such as rendezvous and docking.

2. For the subjects tested there was little, if any, correlation between the average error and the standard deviation. In many cases the average estimates were very accurate, but the corresponding standard deviation was frequently as high as 30 to 40 percent of the true range.

3. The color of the target tested (white and fluorescent orange) had no apparent effect upon the subjects' estimates.

4. The region in which the range estimates for a receding target were accurate increased with an increase in the size of the target. This is to be expected to some degree since the visual angle necessary for resolution of an object is present at greater range with the large objects.

5. Subjects apparently estimated the range for both approaching and receding targets by basing all estimates on an initial judgment which was then updated by adding the apparent distance change in each subsequent observation.

6. It may be possible to extend the region of accuracy for an approaching target if the subject could determine the range at one point during closure from which he could more accurately base subsequent estimations. Several techinques utilizing the pilot's visual acuity appear feasible. An example of such a technique is a geometrical pattern which becomes recognizable at some particular distance.

7. Both the average error and the standard deviation of range estimates made using varied target brightness levels were much higher than those occurring with the fixed (high) brightness level. In addition, average estimations for

the dim observations were less accurate than those at the higher level. Therefore, great care should be taken in relying upon range estimates made under conditions in which apparent target brightness or contrast would vary.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., February 11, 1965.

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TABLE I.- NUMBER OF TESTS PER SUBJECT FOR EACH TARGET

Target	Number of tests for observer - I	II	III	IV	V	VI	Total	Observations per test
5-foot cylinder:								
Approaching	5	1	5	1	5	4	21	10
Receding	2		2		2	2	8	
2.5-foot cylinder:								
Approaching	1		1		1	1	4	10
Receding	1		1		1	1	4	
1.25-foot cylinder:								
Approaching	2		2		2	2	8	11
Receding	2		2		2	2	8	
1-foot-diameter disk:								
Approaching	2		2		2	2	8	20
Receding	3		3		3	3	12	
Triangle:								
Approaching	2		2		2	2	8	12
Receding	2		2		2	2	8	
5-foot cylinder (variable light)	1	1	1	1			4	10

TABLE II.- TYPICAL ESTIMATION RESULTS FOR ONE TEST

[1.25-foot-cylinder target]

True range, ft	Estimated range, ft, for observer -			
	I	III	V	VI
35	45	50	40	50
55	60	75	60	75
75	110	90	90	100
145	160	140	150	175
195	200	200	175	250
295	250	400	225	350
495	350	450	350	600
395	400	380	325	500
295	350	350	300	300
595	450	600	500	600

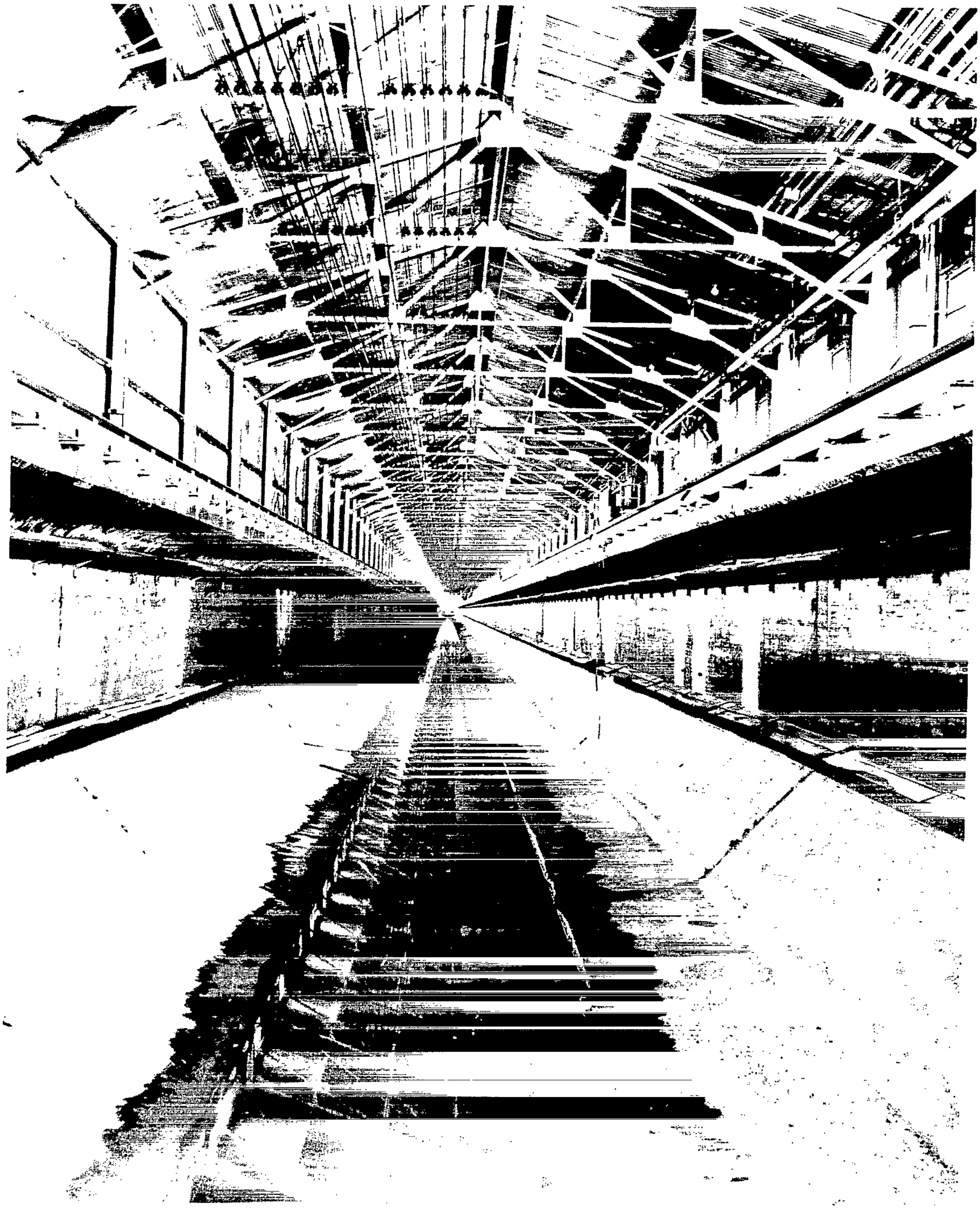


Figure 1.- High-speed phenomena division of David Taylor model basin. L-63-9780

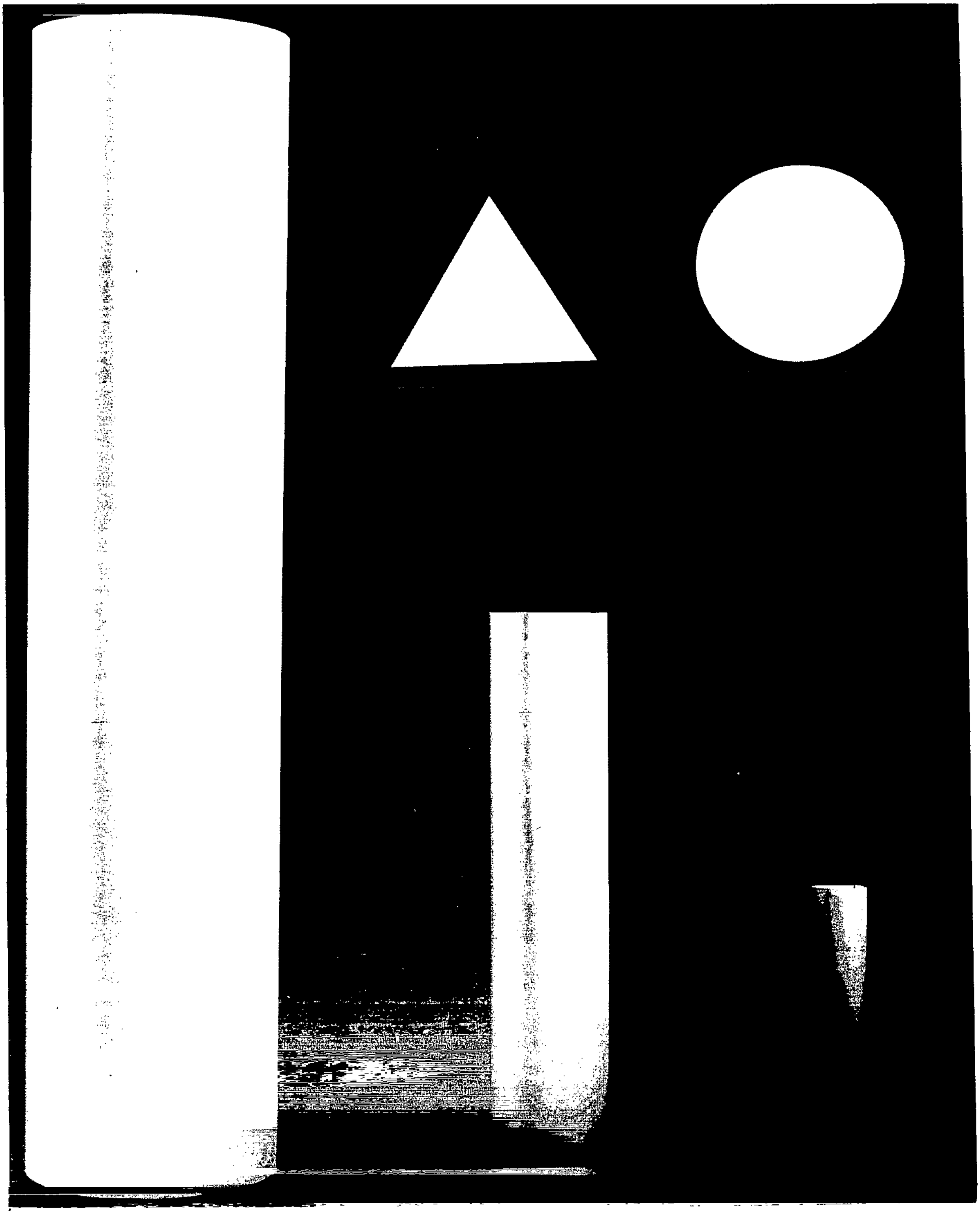


Figure 2.- Targets employed. L-63-5147

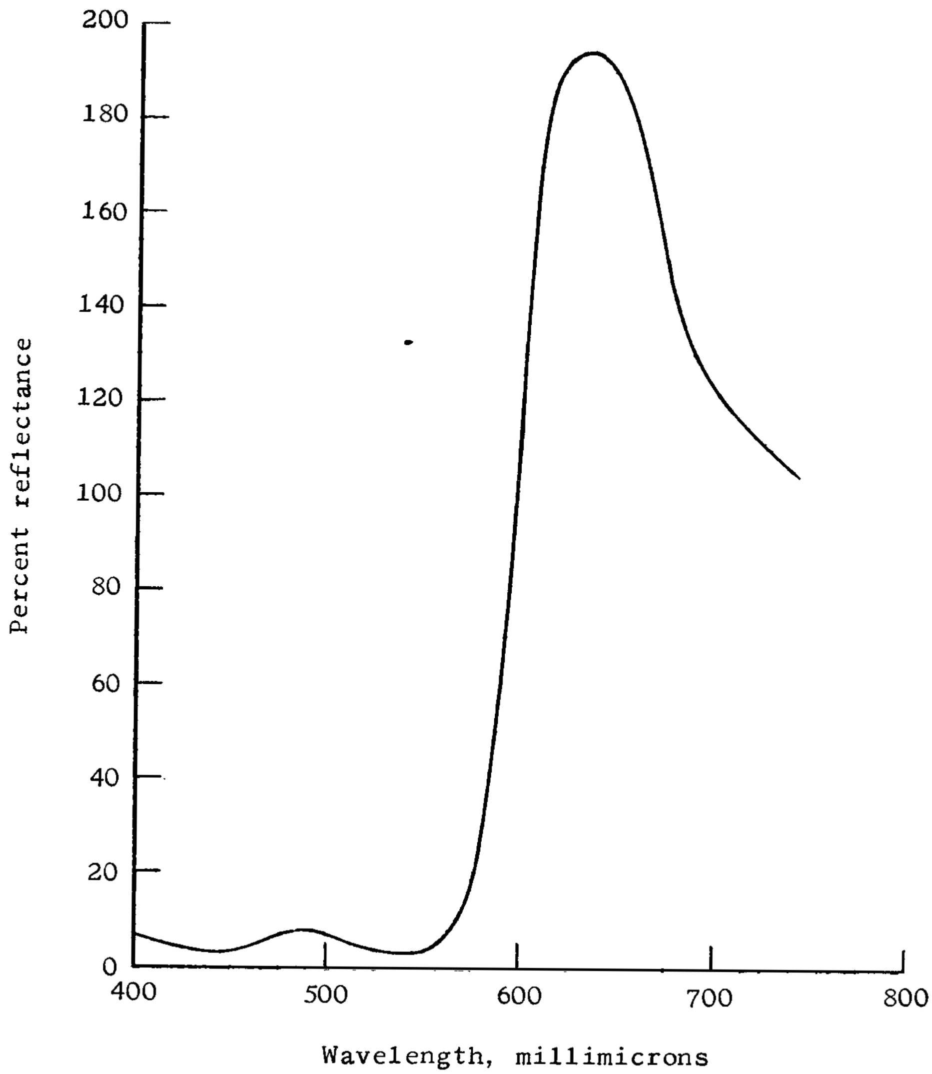


Figure 3.- Spectral reflectance for fluorescent orange paint.

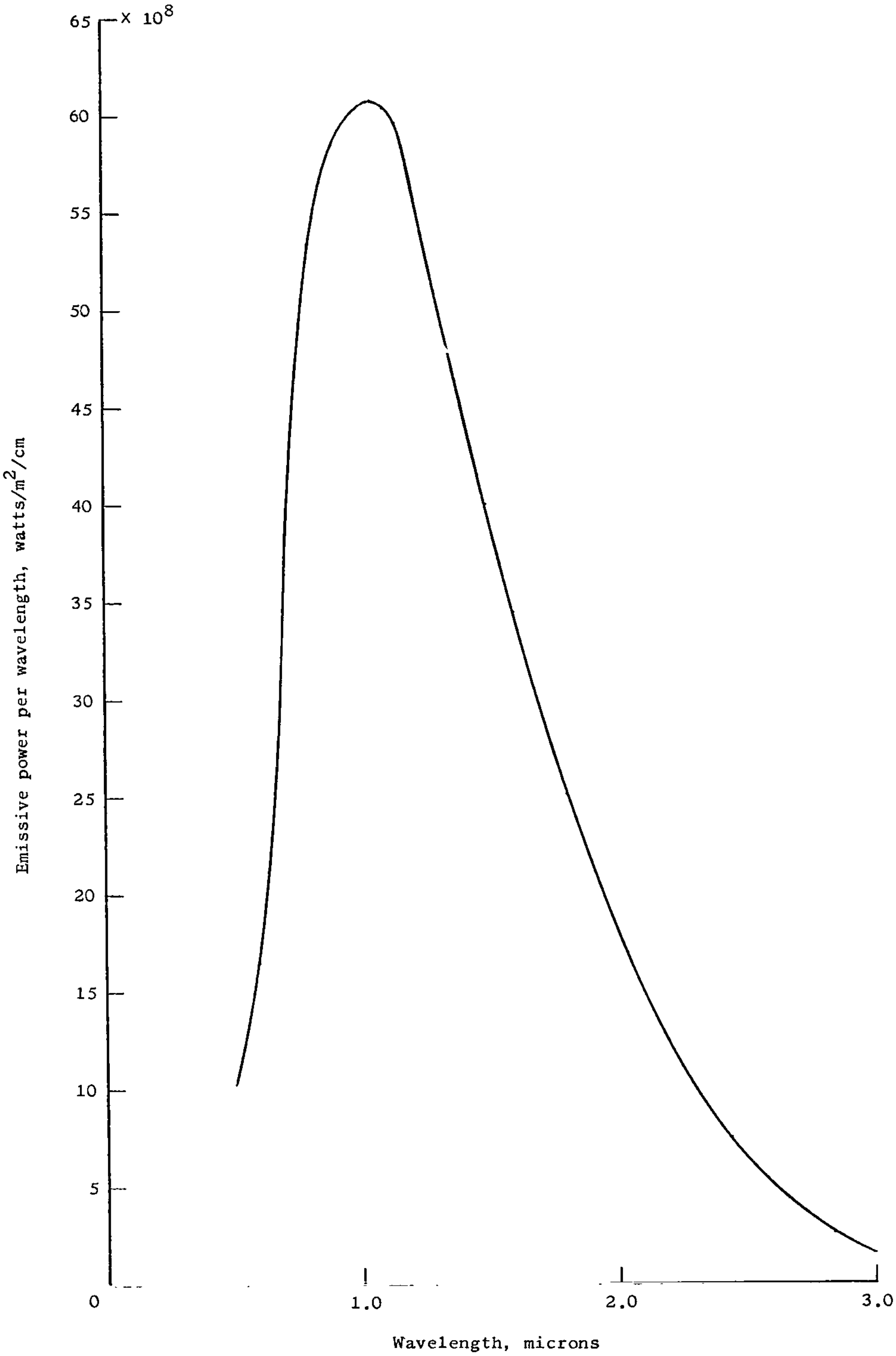


Figure 4.- Spectral distribution of sealed-beam lantern used in experiments.

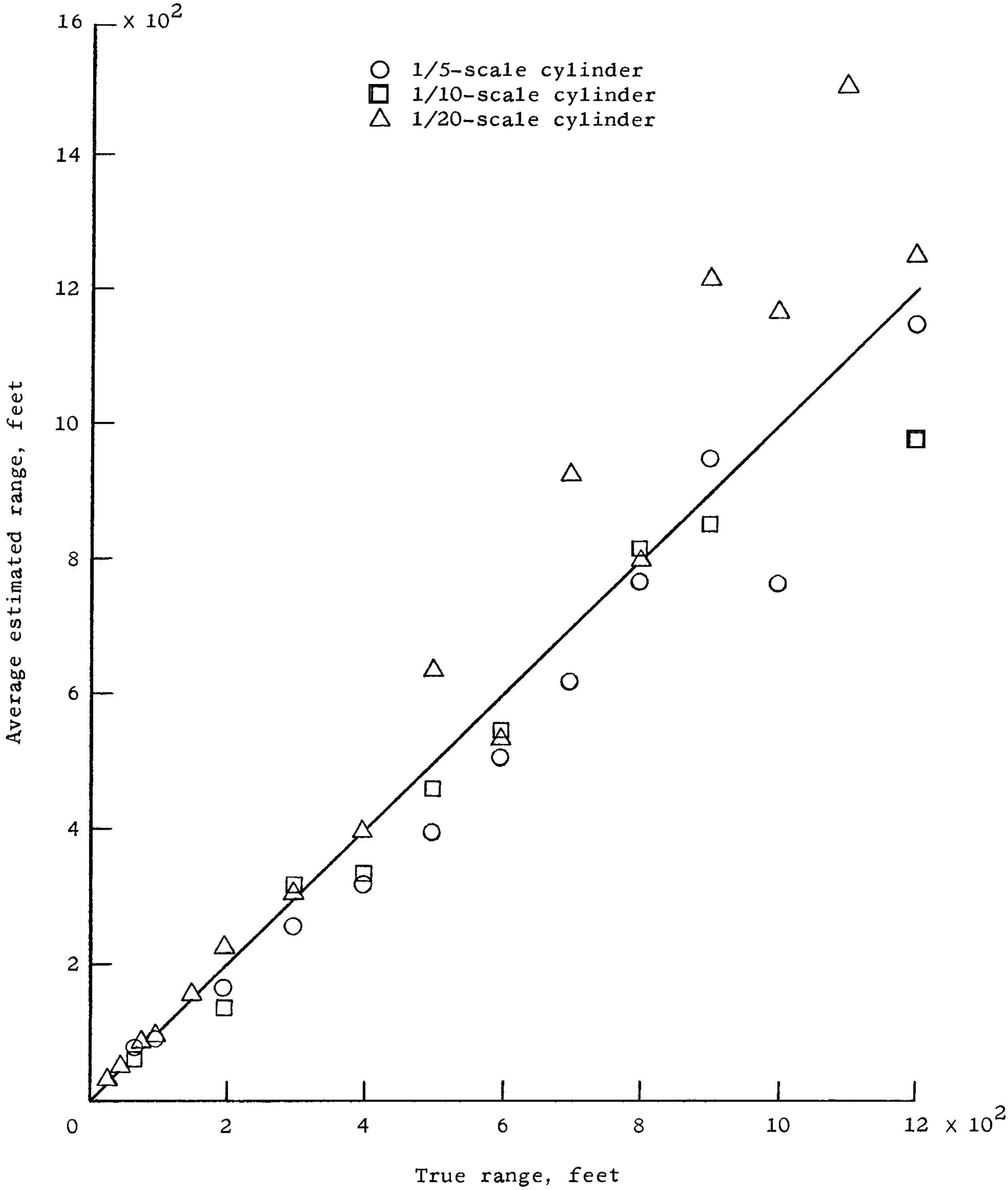
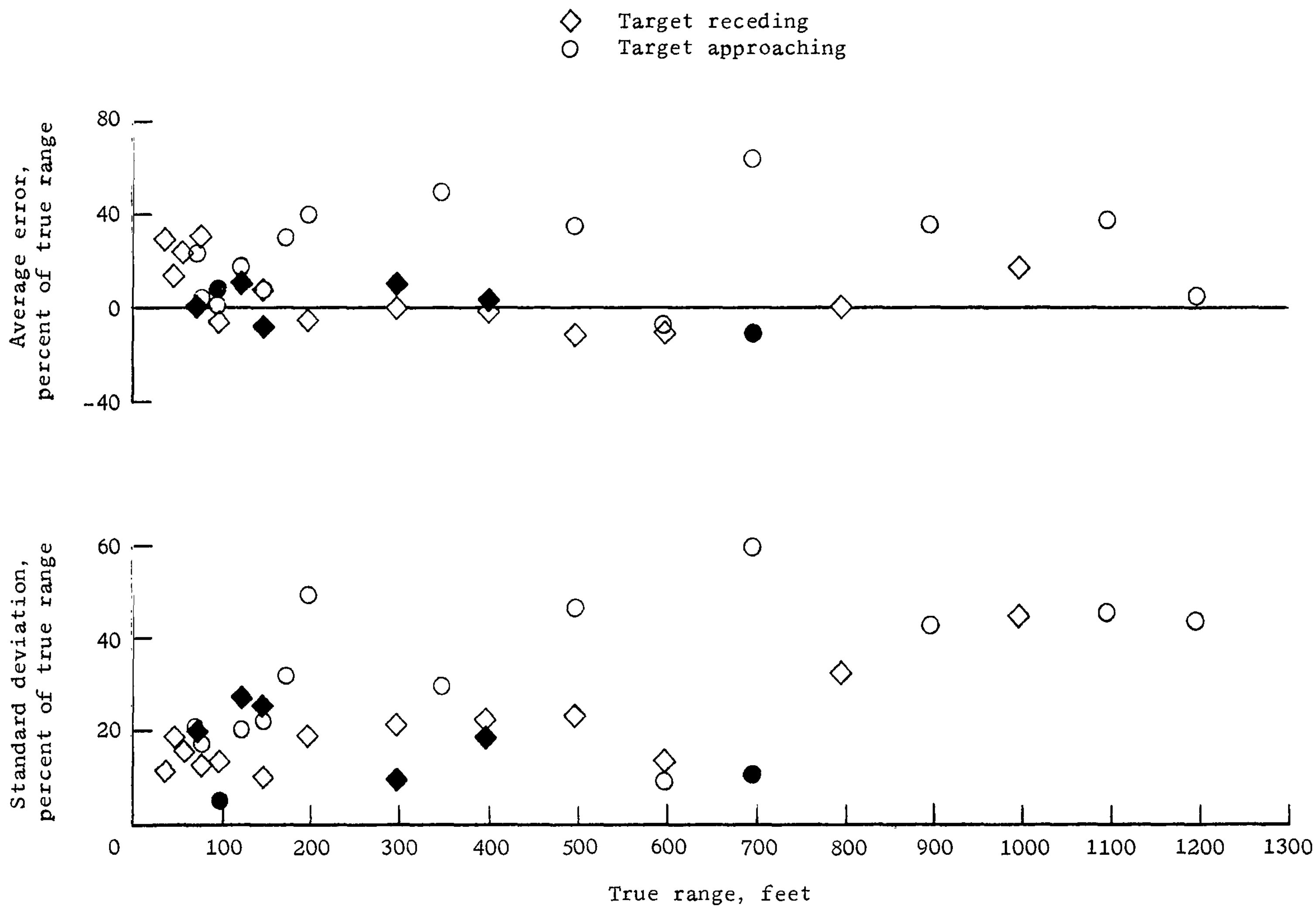
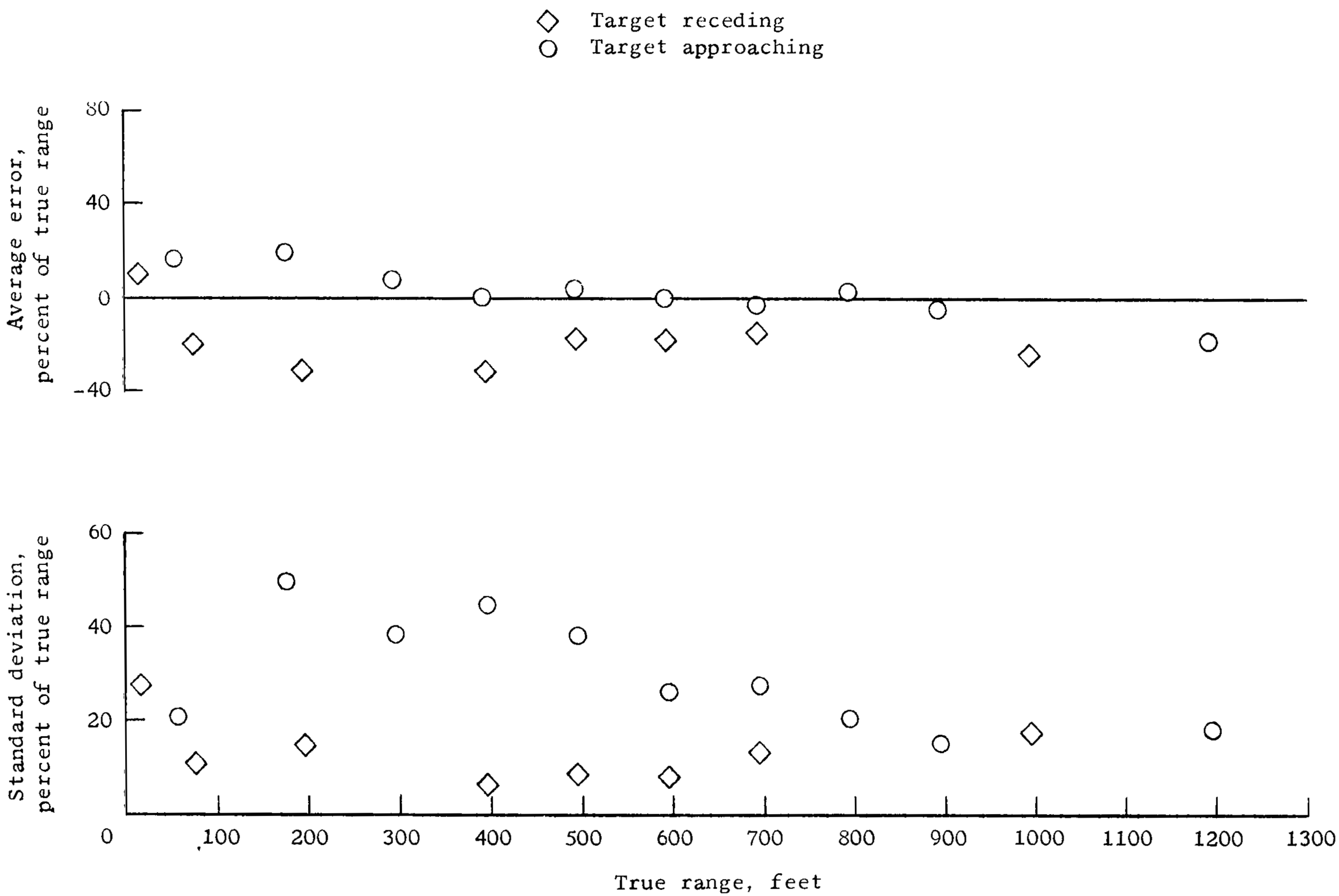


Figure 5.- Average distance estimations for cylindrical targets.



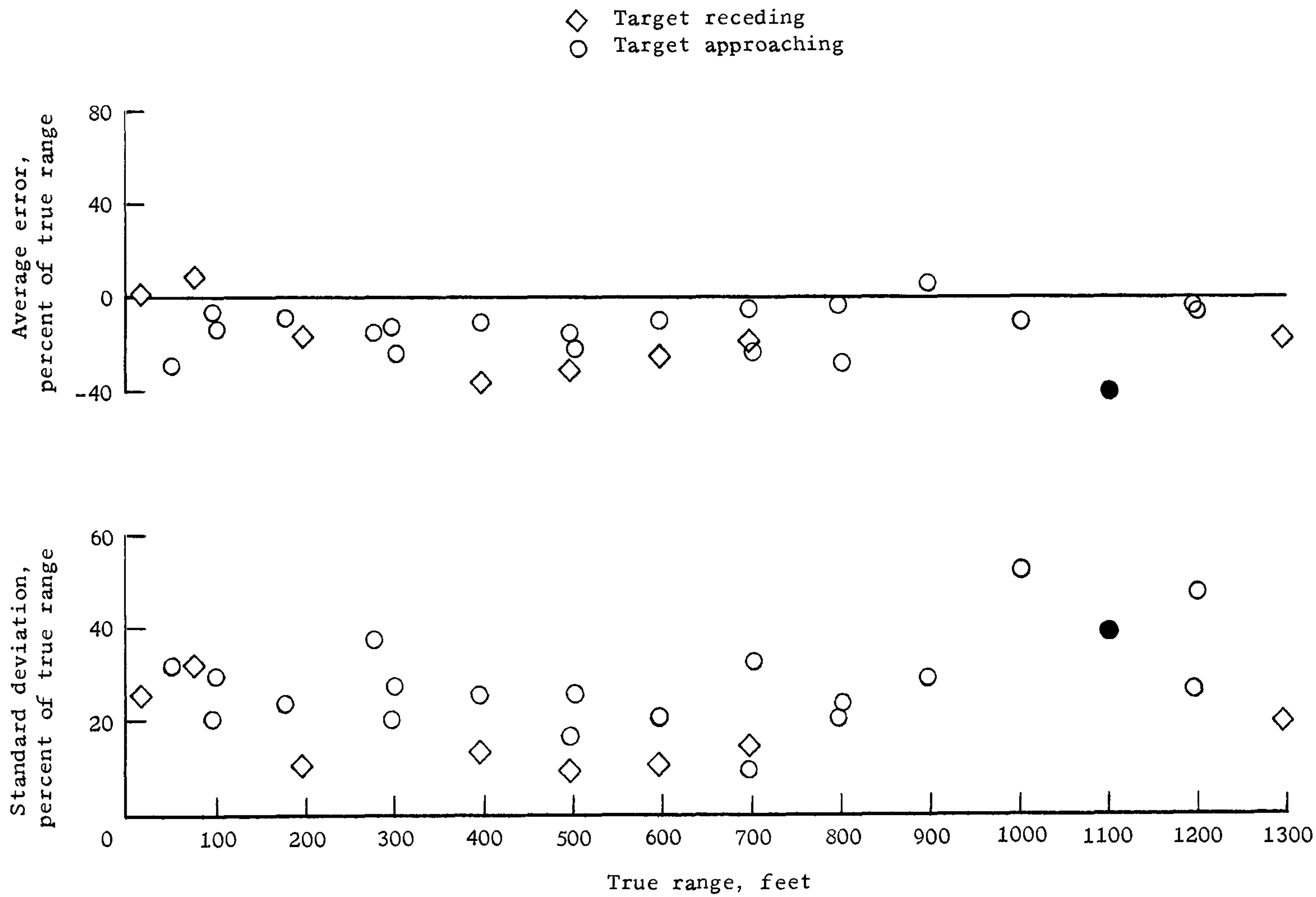
(a) 1/20-scale cylinder.

Figure 6.- Average error and standard deviation plotted against true range. (Solid symbols indicate reversal of general direction.)



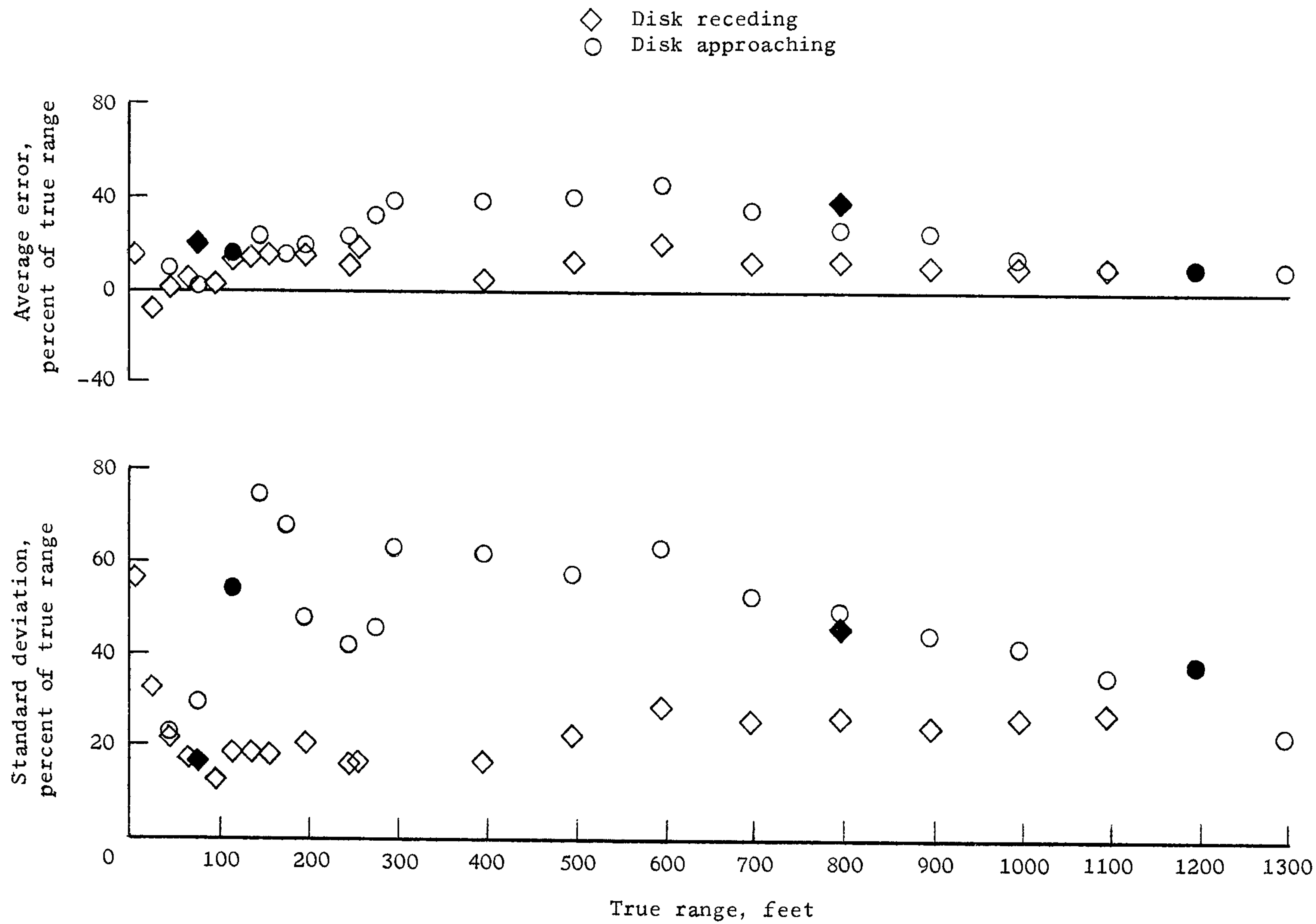
(b) 1/10-scale cylinder.

Figure 6.- Continued.



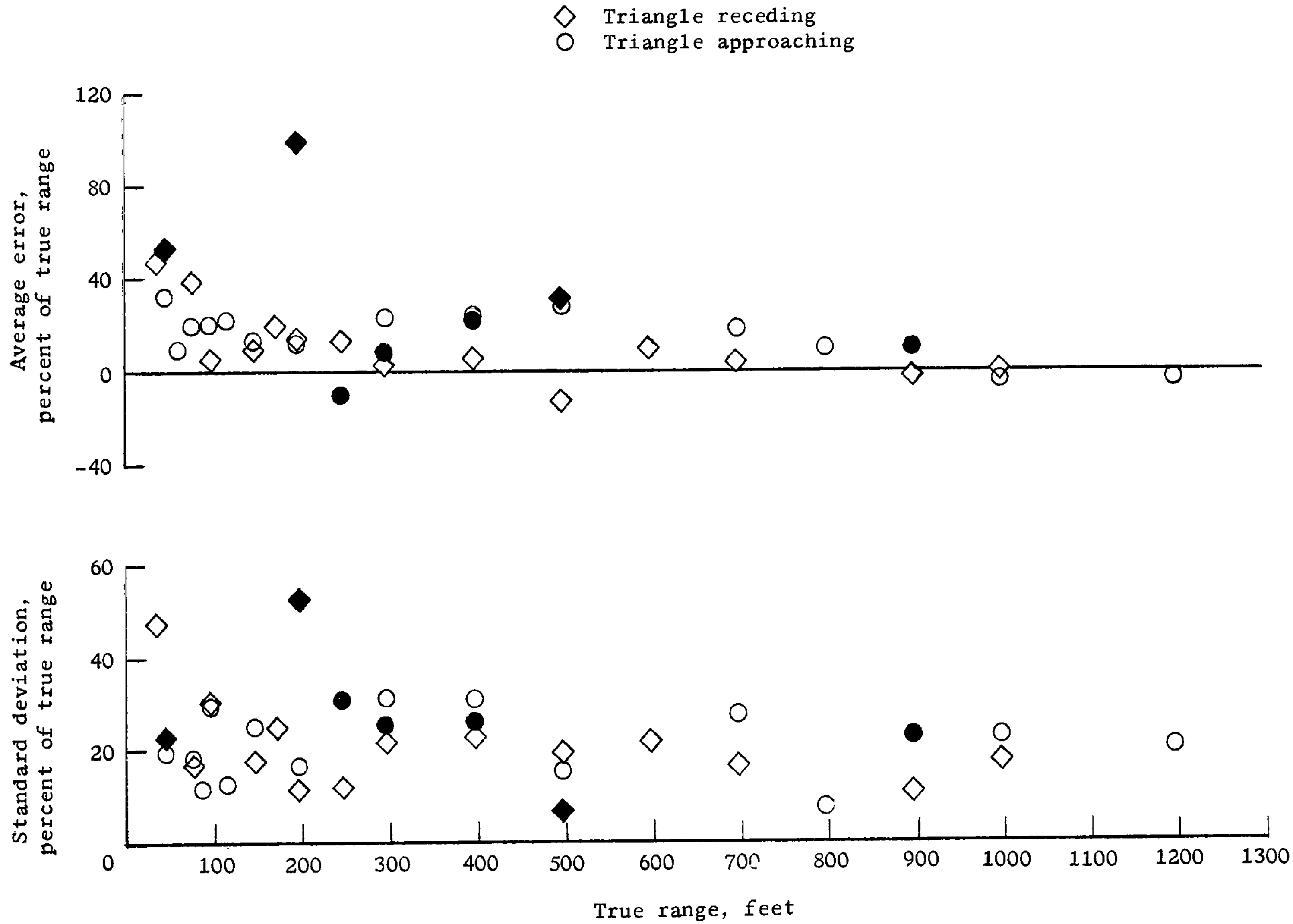
(c) 1/5-scale cylinder.

Figure 6.- Continued.



(d) 1-foot-diameter disk.

Figure 6.- Continued.



(e) Triangle.

Figure 6.- Concluded.

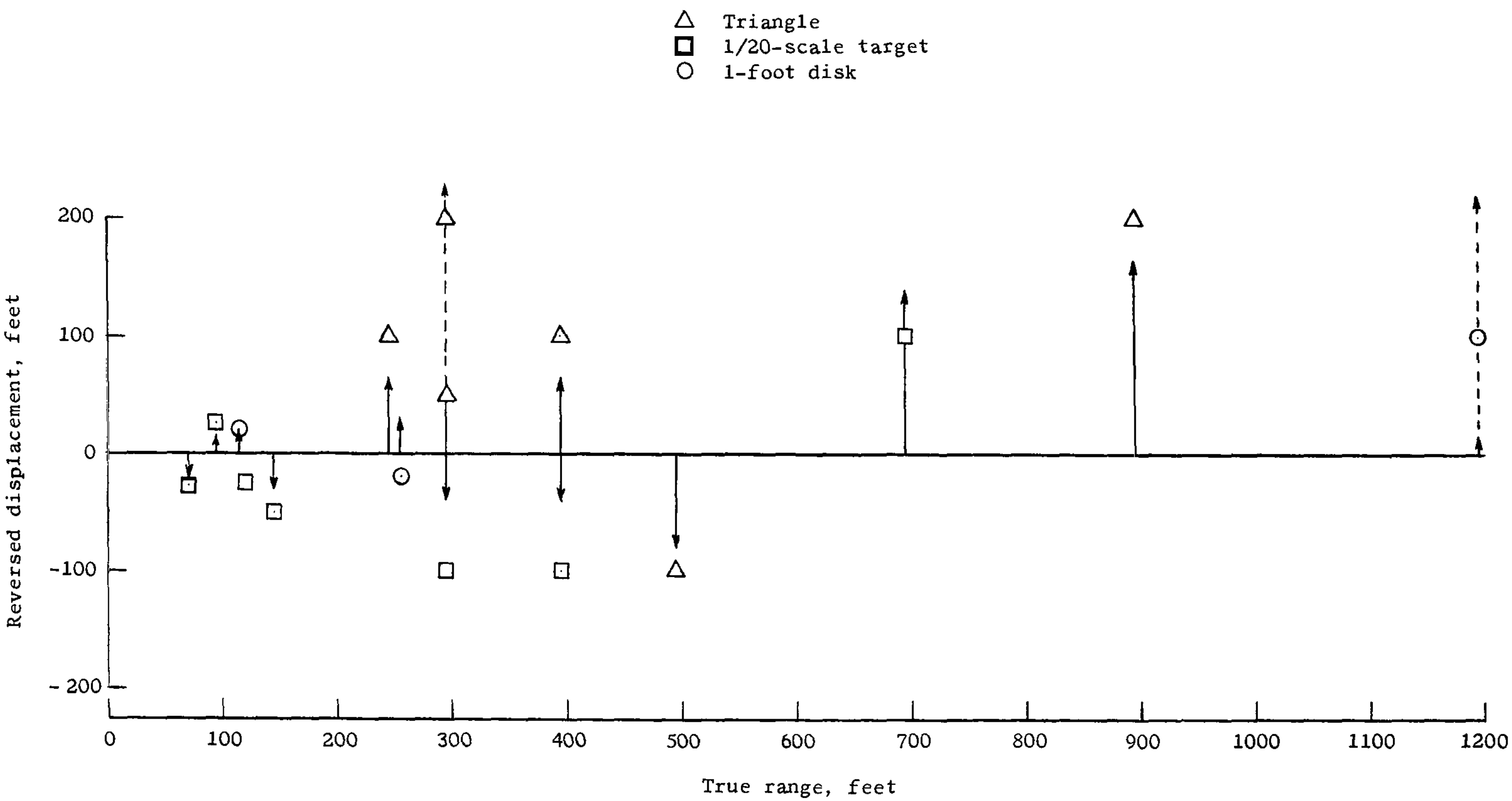


Figure 7.- Average estimations during reversed displacement. (Arrows indicate estimates; dashed lines indicate two estimates, at same range; data symbols indicate actual target displacement.)

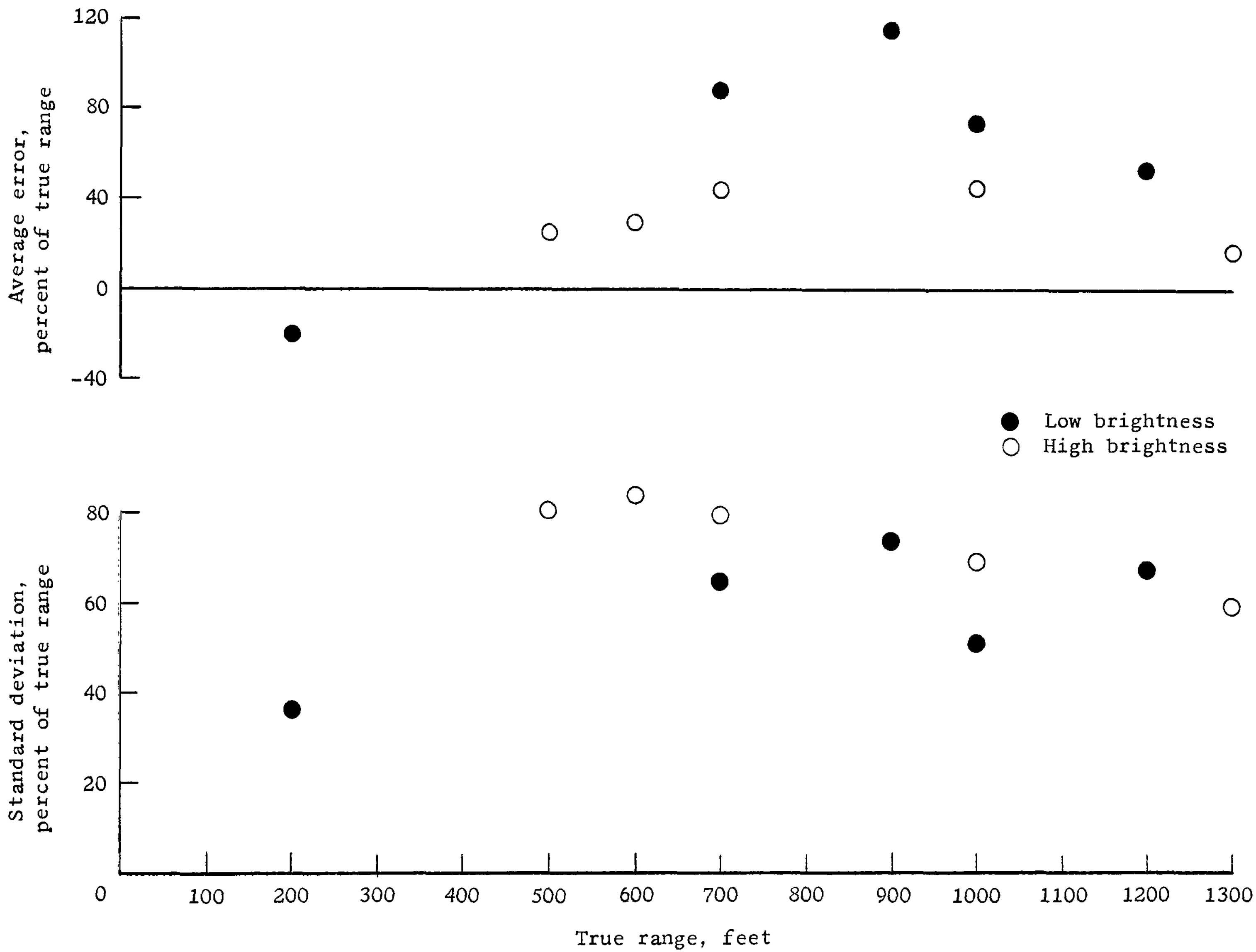


Figure 8.- Effect of brightness of model on range estimations.

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